Chapter 2 - Elements, compounds and mixtures

Elements
- Atoms — the smallest particles
- Molecules

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- More about formulae
- Balancing chemical equations
- Instrumental techniques

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- What is the difference between mixtures and compounds?

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- Separating liquid/liquid mixtures
- Separating solid/solid mixtures

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Additional questions

The universe is made up of a very large number of substances (Figure 2.1), and our own world is no exception. If this vast array of substances is examined more closely, it is found that they are made up of some basic substances which were given the name **elements** in 1661 by Robert Boyle, who we met in Chapter 1.

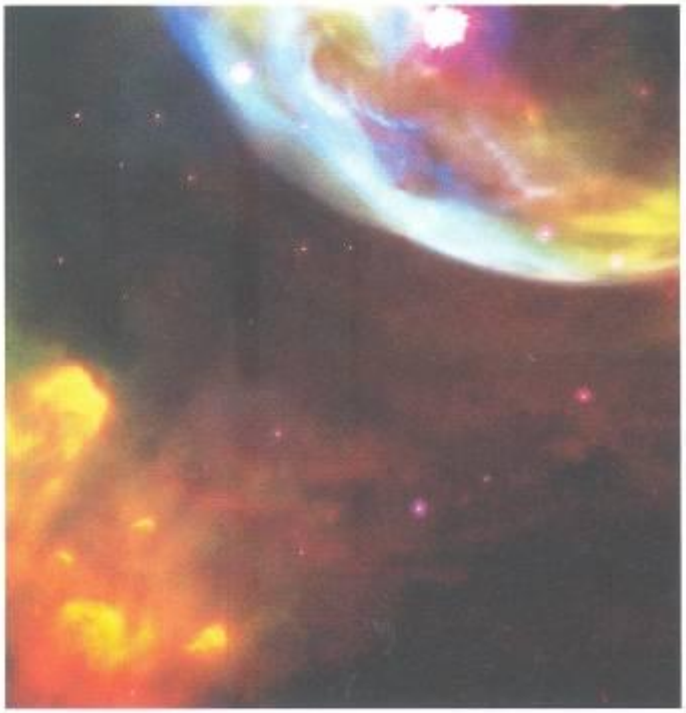


Figure 2.1 The planets in the universe are made of millions of substances. These are made up mainly from just 91 elements which occur naturally on the Earth.

In 1803, John Dalton (Figure 2.2) suggested that each element was composed of its own kind of particles, which he called **atoms**. Atoms are much too small to be seen. We now know that about 20×10^6 of them would stretch over a length of only 1 cm.

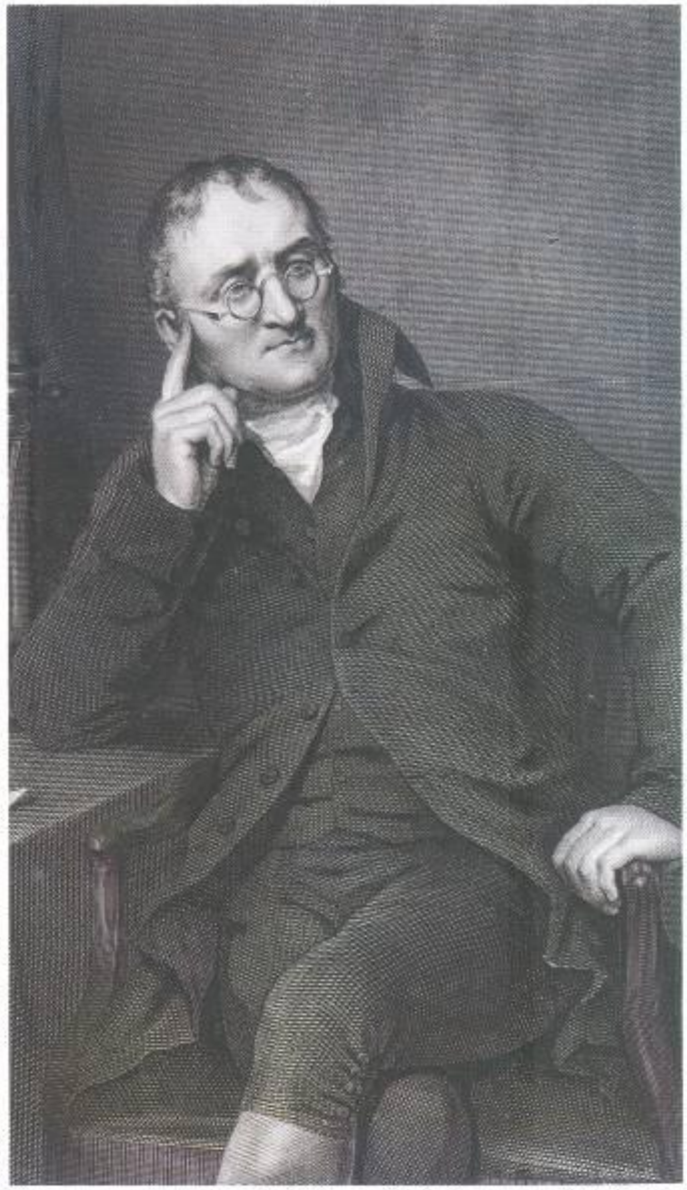


Figure 2.2 John Dalton (1766–1844).

Elements

Robert Boyle used the name element for any sub-stance that cannot be broken down further, into a simpler substance. This definition can be extended to include the fact that each element is made up of only one kind of atom. The word atom comes from the Greek word atomos meaning 'unsplittable'.

For example, aluminium is an element which is made up of only aluminium atoms. It is not possible to obtain a simpler substance chemically from the aluminium atoms. You can only make more complicated substances from it, such as aluminium oxide, aluminium nitrate or aluminium sulphate.

There are 115 elements which have now been identified. Twenty-four of these do not occur in nature and have been made artificially by scientists. They include elements such as plutonium, curium and unnilpentium. Ninety-one of the elements occur naturally and range from some very reactive gases, such as fluorine and chlorine, to gold and platinum, which are unreactive elements.

a Gold is very decorative.

b Titanium has many uses in the aerospace industry.

c These coins contain nickel.

Figure 2.3 Some metals.

All elements can be classified according to their various properties. A simple way to do this is to classify them as **metals** or **non-metals** (Figures 2.3 and 2.4). Table 2.1 shows the physical data for some common metallic and non-metallic elements.

You will notice that many metals have high densities, high melting points and high boiling points, and that most non-metals have low densities, low melting points and low boiling points. Table 2.2 summarises the different properties of metals and non metals.

A discussion of the chemical properties of metals is given in Chapters 3, 4 and 9. The chemical properties of certain non-metals are discussed in Chapters 3, 4, 15 and 16.

Table 2.1 Physical data for some metallic and non-metallic elements at room temperature and pressure.

Element	**Metal or non-metal**	**Density/$g\cdot cm^{-3}$**	**Melting point/°C**	**Boiling point/°C**
Aluminium	Metal	2.70	660	2580
Copper	Metal	8.92	1083	2567
Gold	Metal	19.29	1065	2807
Iron	Metal	7.87	1535	2750
Lead	Metal	11.34	328	1740
Magnesium	Metal	1.74	649	1107
Nickel	Metal	8.90	1453	2732
Silver	Metal	10.50	962	2212
Zinc	Metal	7.14	420	907
Carbon	Non-metal	2.25	2652	Sublimes
Hydrogen	Non-metal	0.07[a]	-259	-253
Nitrogen	[1] Non-metal	0.88[b]	-210	-196
Oxygen	Non-metal	1.15[c]	-218	-183
Sulphur	Non-metal	2.07	113	445

Source: Earl B., Willford L.D.R. Chemistry data book. Nelson Blackie, 1991
[a] At -254 °C [b] At -197 °C [c] At -184 °C.

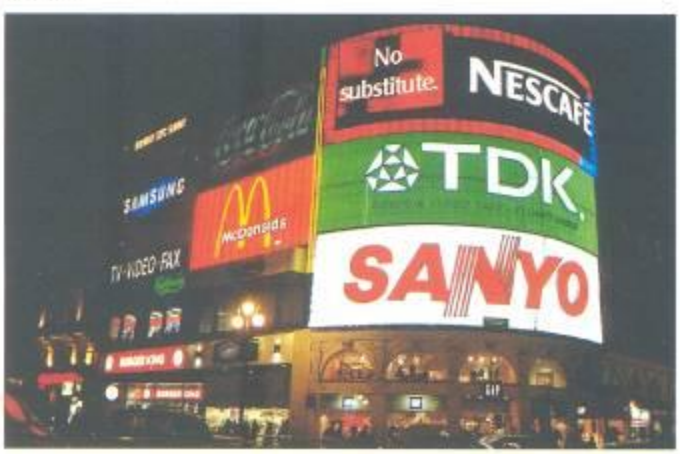
Table 2.2 How the properties of metals and non-metals compare.

Property	**Metal**	**Non-metal**
Physical state at room temperature	Usually solid (occasionally liquid)	Solid, liquid or gas
Malleability	Good	No – usually soft or brittle when solid
Ductility	Good	
Appearance (solids)	Shiny (lustrous)	Dull

Melting point	Usually high	Usually low
Boiling point	Usually high	Usually low
Density	Usually high	Usually low
Conductivity (thermal and electrical)	Good	Very poor

a A premature baby needs oxygen.

b Artists often use charcoal (carbon) to produce an initial sketch.



c Neon is used in advertising signs.

Figure 2.4 Some non-metals.

Atoms - the smallest particles

Everything is made up of billions of atoms. The atoms of all elements are extremely small; in fact they are too small to be seen. The smallest atom known is hydrogen, with each atom being represented as a sphere having a diameter of 0.000 000 07 mm (or 7×10^{-8} mm) (Table 2.3). Atoms of different elements have different diameters as well as different masses. How many atoms of hydrogen would have to be placed side by side along the edge of your ruler to fill just one of the 1 mm division?

Chemists use shorthand symbols to label the elements and their atoms. The symbol consists of one, two or three letters, the first of which must be a capital. Where several elements have the same initial letter, a second letter of the name or subsequent letter is added. For example, **C** is used for **carbon**, **Ca** for **calcium** and **Cl** for **chlorine**. Some symbols seen to have no relationship to the name of the element, for

example **Na** for **sodium** and **Pb** for **lead**. These symbols come from their Latin names, natrium for sodium and plumbum for lead. A list of some common elements and their symbols is given in Table 2.4.

Table 2.3 Sizes of atoms.

Atom	Diameter of atom/mm
Hydrogen	7×10^{-8}
Oxygen	12×10^{-8}
Sulphur	20.8×10^{-8}

Table 2.4 Some common elements and their symbols.

Element	**Symbol**	**Physical state at room temperature and pressure**
Aluminium	Al	Solid
Argon	Ar	Gas
Barium	Ba	Solid
Boron	B	Solid
Bromine	Br	Liquid
Calcium	Ca	Solid
Carbon	C	Solid
Chlorine	Cl	Gas
Chromium	Cr	Solid
Copper	Cu	Solid (Cuprum)
Fluorine	F	Gas
Germanium	Ge	Solid
Gold	Au	Solid (Aurum)
Helium	He	Gas
Hydrogen	H	Gas
Iodine	I	Solid
Iron (Ferrum)	Fe	Solid
Lead (Plumbum)	Pb	Solid
Magnesium	Mg	Solid
Mercury (Hydragyrum)	Hg	Liquid
Neon	Ne	Gas
Nitrogen	N	Gas
Oxygen	O	Gas

Phosphorus	P	Solid
Potassium (Kalium)	K	Solid
Silicon	Si	Solid
Silver (Argentum)	Ag	Solid
Sodium (Natrium)	Na	Solid
Sulphur	S	Solid
Tin (Stannum)	Sn	Solid
Zinc	Zn	Solid

Molecules

The atoms of some elements are joined together in small groups. These small groups of atoms are called **molecules**. For example, the atoms of the elements hydrogen, oxygen, nitrogen, fluorine, chlorine, bromine and iodine are each joined in pairs and they are known as **diatomic** molecules. In the case of phosphorus and sulphur the atoms are joined in larger numbers, four and eight respectively (P_4, S_8). In chemical shorthand the molecule of chlorine shown in Figure 2.5 is written as Cl_2.

a As a letter-and-stick model.

b As a space-filling model.

Figure 2.5 A chlorine molecule.

The gaseous elements helium, neon, argon, krypton, xenon and radon are composed of separate and individual atoms. When an element exists as separate atoms, then the molecules are said to be **monatomic**. In chemical shorthand these monatomic molecules are written as He, Ne, Ar, Kr, Xe and Rn respectively.

Molecules are not always formed by atoms of the same type joining together. For example, water exists as molecules containing oxygen and hydrogen atoms.

Questions

1. How would you use a similar chemical shorthand to write a representation of the molecules of iodine and fluorine?

2. Using the periodic table on page 40 write down the symbols for the following elements and give their physical states at room temperature.

a. chromium
b. krypton
c. osmium.

Compounds

Compounds are pure substances which are formed when two or more elements chemically combine together. Water is a simple compound formed from the elements hydrogen and oxygen (Figure 2.6). This combining of the elements can be represented by a word equation:

hydrogen + oxygen → water

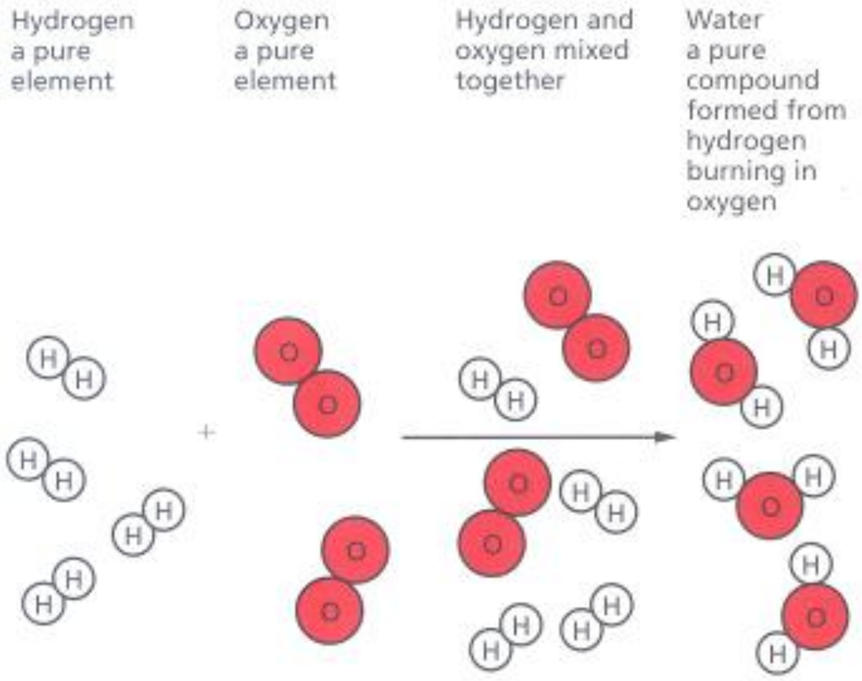


Figure 2.6 The element hydrogen reacts with the element oxygen to produce the compound water.

Water molecules contain two atoms of hydrogen and one atom of oxygen, and hence water has the **chemical formula** H_2O. Elements other than hydrogen will also react with oxygen to form compounds called oxides. For example, magnesium reacts violently with oxygen gas to form the white powder magnesium oxide (Figure 2.7). This reaction is accompanied by a release of energy as new chemical bonds are formed.

When a new substance is formed during a chemical reaction, a **chemical change** has taken place.

magnesium + oxygen → magnesium oxide

When substances such as hydrogen and magnesium combine with oxygen in this way they are said to have been **oxidised**. The process is known as **oxidation**.

Reduction is the opposite of oxidation. In this process oxygen is removed instead of being added. For example, the oxygen has to be removed in the extraction of iron from iron (III) oxide. This can be done in a blast furnace with carbon monoxide. The iron(m) oxide loses oxygen to the carbon monoxide and is reduced to iron while carbon monoxide is oxidised to carbon dioxide. You will deal in more detail with this extraction process in Chapter 9.

iron (III) oxide + carbon monoxide → iron + carbon dioxide

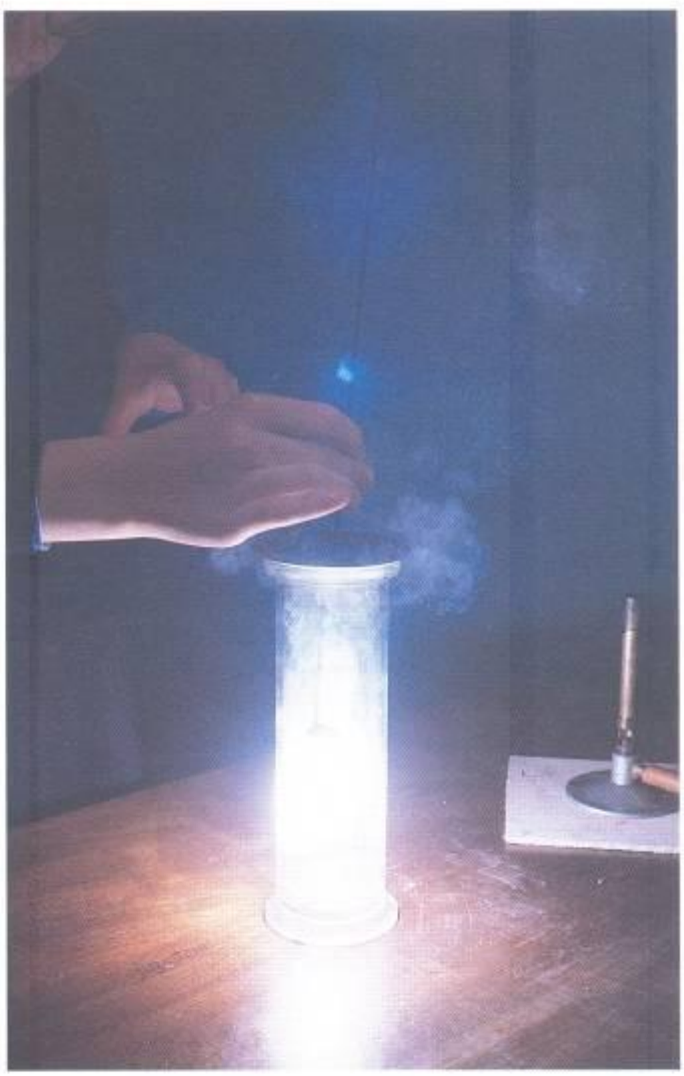


Figure 2.7 Magnesium burns brightly in oxygen to produce magnesium oxide.

Both **red**uction and **ox**idation have taken place in this chemical process, and so this is known as a **redox** reaction. A further discussion of oxidation and reduction takes place in Chapter 6.

More about formulae

The formula of a compound is made up from the symbols of the elements present and numbers to show the ratio in which the different atoms are present. Carbon dioxide has the formula CO,. This tells you that it contains one carbon atom for every two oxygen atoms. The 2 in the formula tells you that there are two oxygen atoms present in each molecule of carbon dioxide.

Table 2.5 shows the names and formulae of some common compounds which you will meet in your study of chemistry.

The ratio of atoms within a chemical compound is usually constant. Compounds are made up of fixed pro-portions of elements: they have a fixed composition. Chemists call this the **Law of constant composition**.

Table 2.5 Names and formulae of some common compounds.

Compound	**Formula**
Ammonia	NH_3
Calcium hydroxide	$Ca(OH)_2$
Carbon dioxide	CO_2
Copper sulphate	$CuSO_4$
Ethanol (alcohol)	C_2H_5OH
Glucose	$C_6H_{12}O_6$
Hydrochloric acid	HCl
Nitric acid	HNO_3
Sodium carbonate	Na_2CO_3
Sodium hydroxide	$NaOH$
Sulphuric acid	H_2SO_4

Balancing chemical equations

Word equations are a useful way of representing chemical reactions but a better and more useful method is to produce a **balanced chemical equation**. This type of equation gives the formulae of the reactants and the products as well as showing the relative numbers of each particle involved. Balanced equations often include the physical state symbols:

(s) = solid, (l) = liquid, (g) = gas, (aq) = aqueous solution

The word equation to represent the reaction between iron and sulphur is:

$$\text{iron} + \text{sulphur} \xrightarrow{\text{heat}} \text{iron (II) sulphide}$$

When we replace the words with symbols for the reactants and the products and include their physical state symbols, we obtain:

$$Fe(s) + S(s) \xrightarrow{\text{heat}} FeS(s)$$

Since there is the same number of each type of atom on both sides of the

equation this is a **balanced** chemical equation.

In the case of magnesium reacting with oxygen, the word equation was:

$$\text{magnesium} + \text{oxygen} \xrightarrow{\text{heat}} \text{magnesium oxide}$$

When we replace the words with symbols for the reactants and the products and include their physical state symbols, it is important to remember that oxygen is a diatomic molecule:

$$Mg\,(s) + O_2\,(g) \xrightarrow{\text{heat}} MgO\,(s)$$

In the equation there are two oxygen atoms on the left-hand side (O_2) but only one on the right (MgO). We cannot change the formula of magnesium oxide, so to produce the necessary two oxygen atoms on the right-hand side we will need 2MgO — this means 2 × MgO. The equation now becomes:

$$Mg\,(s) + O_2\,(g) \xrightarrow{\text{heat}} 2MgO\,(s)$$

There are now two atoms of magnesium on the right-hand side and only one on the left. By placing a 2 in front of the magnesium, we obtain the following balanced chemical equation:

$$2Mg\,(s) + O_2\,(g) \xrightarrow{\text{heat}} 2MgO\,(s)$$

This balanced chemical equation now shows us that two atoms of magnesium react with one molecule of oxygen gas when heated to produce two units of magnesium oxide.

Instrumental techniques

Elements and compounds can be detected and identified by a variety of instrumental methods. Scientists have developed instrumental techniques that allow us to probe and discover which elements are present in the substance as well as how the atoms are arranged within the substance.

Many of the instrumental methods that have been developed are quite

sophisticated. Some methods are suited to identifying elements. For example, atomic absorption spectroscopy allows the element to be identified and also allows the quantity of the element that is present to be found (Figure 2.8).

Figure 2.8 This instrument allows the quantity of a particular element to be found. It is used extensively throughout industry for this purpose. It will allow even tiny amounts of a particular element to be found.

Some methods are particularly suited to the identification of compounds. For example, infrared spectroscopy is used to identify compounds by showing the presence of particular groupings of atoms (Figure 2.9).

Infrared spectroscopy is used by the pharmaceutical industry to identify and discriminate between drugs that are similar in structure, for example penicillin-type drugs. Used both with organic and inorganic molecules, this method assumes that each compound has a unique infrared spectrum. Samples can be solid, liquid or gas and are tiny. However, Ne, He, O_2, N_2 or H_2 cannot be used.

This method is also used to monitor environmental pollution, and has biological uses in monitoring tissue physiology including oxygenation,

respiratory status and blood flow damage.

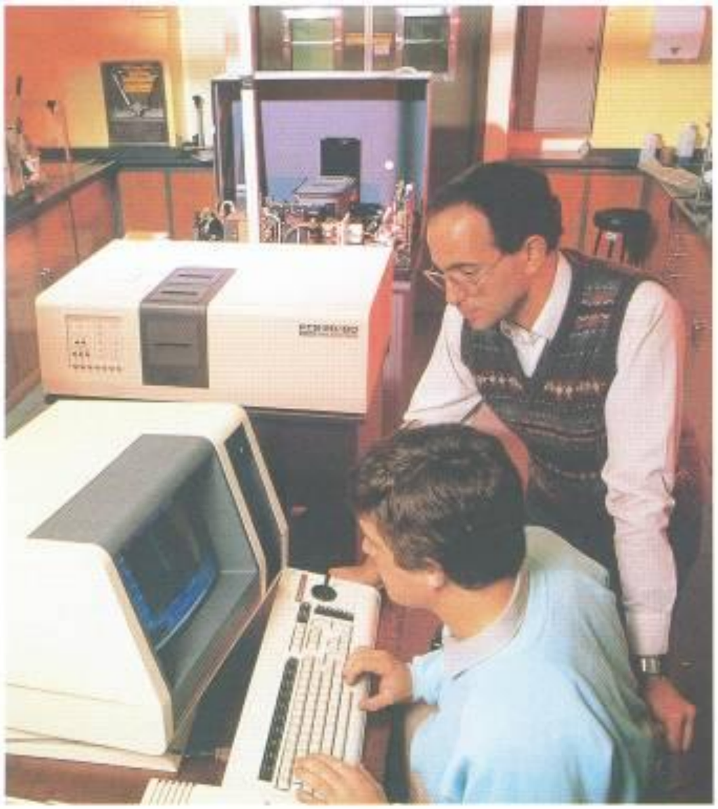


Figure 2.9 This is a modern infrared spectrometer. It is used in analysis to obtain a so-called fingerprint spectrum of a substance that will allow the substance to be identified.

Forensic scientists make use of both these techniques because they are very accurate but they only require tiny amounts of sample — often only small amounts of sample are found at crime scenes. Other techniques utilised are nuclear magnetic resonance spectroscopy and ultraviolet/ visible spectroscopy.

Questions

1. Write the word and balanced chemical equations for the reactions which take place between:

a. calcium and oxygen
b. copper and oxygen.

2. Write down the ratio of the atoms present in each formula for each of the compounds shown in Table 2.5.

3. Iron is extracted from iron(iii) oxide in a blast furnace by a redox reaction. What does the term 'redox reaction' mean?

Mixtures

Many everyday things are not pure substances, they are mixtures. A mixture contains more than one substance (elements and/or compounds). An example of a common mixture is sea water (Figure 2.10).

Figure 2.10 Sea water is a common mixture.

What is the difference between mixtures and compounds?

Figure 2.11 The elements (left to right) iron and sulphur, and below a mixture of iron and sulphur and black iron(II) sulphide.

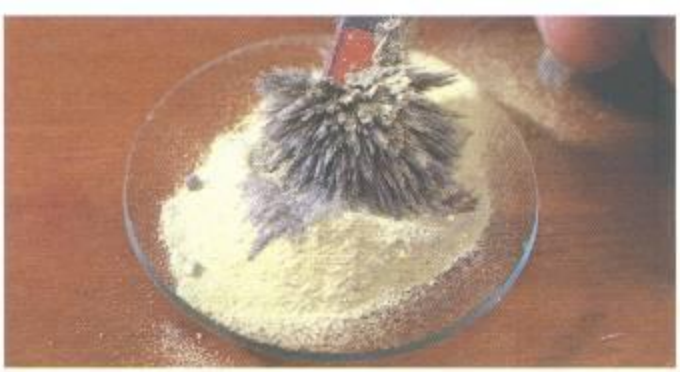


Figure 2.12 A magnet will separate the iron from the mixture.

There are differences between compounds and mixtures. This can be shown by considering the reaction between iron filings and sulphur. A mixture of iron filings and sulphur looks different from the individual elements (Figure 2.11). This mixture has the properties of both iron and sulphur; for example, a magnet can be used to separate the iron filings from the sulphur (Figure 2.12).

Substances in a mixture have not undergone a chemical reaction and it is possible to separate them provided that

there is a suitable difference in their physical properties (p. 25). If the mixture of iron and sulphur is heated a chemical reaction occurs and a new substance is formed called iron (II) sulphide (Figure 2.11). The word equation for this reaction is:

$$\text{iron} + \text{sulphur} \xrightarrow{\text{heat}} \text{iron (II) sulphide}$$

During the reaction heat energy is given out as new chemical bonds are formed. This is called an **exothermic** reaction and accompanies a chemical change (Chapter 13). The iron (II) sulphide formed has totally different properties to the mixture of iron and sulphur (Table 2.6). Iron (III) sulphide, for example, would not be attracted towards a magnet.

In iron(II) sulphide, FeS, one atom of iron has combined with one atom of sulphur. No such ratio exists in a mixture of iron and sulphur, because the atoms have not chemically combined. Table 2.7 summarises how mixtures and compounds compare.

Separating mixtures

Many mixtures contain useful substances mixed with unwanted material. In order to obtain these useful sub-stances, chemists often have to separate them from the impurities. Chemists have developed many different methods of separation, particularly for separating compounds from complex mixtures. Which separation method they use depends on what is in the mixture and the properties of the substances present. It also depends on whether the substances to be separated are solids, liquids or gases.

Separating solid/liquid mixtures

If a solid substance is added to a liquid it may **dissolve** to form a **solution**. In this case the solid is said to be **soluble** and is called the **solute**. The liquid it has dissolved in is called the **solvent**. An example of this type of process is when sugar is added to tea or coffee. What other examples can you think of where this type of process takes place?

Sometimes the solid does not dissolve in the liquid. This solid is said to be **insoluble**. For example, tea leaves themselves do not dissolve in boiling water when tea is made from them, although the soluble materials from which tea is made are seen to dissolve from them.

Table 2.6 Different properties of iron, sulphur, an iron/sulphur mixture and iron (II) sulphide.

Substance	Appearance	Effect of a magnet	Effect of dilute hydrochloric acid
Iron	Dark grey powder	Attracted to it	Very little action when cold. When warm, a gas is produced with a lot of bubbling (effervescence)
Sulphur	Yellow powder	None	No effect when hot or cold
Iron/sulphur mixture	Dirty yellow powder	Iron powder attracted to it	Iron powder reacts as above
Iron (II) sulphide	Dark grey solid	No effect	A foul-smelling gas is produced with some effervescence

Table 2.7 The major differences between mixtures and compounds.

Mixture	Compound
It contains two or more substances	It is a single substance
The composition can vary	The composition is always the same
No chemical change takes place when a mixture is formed	When the new substance is formed it involves chemical change
The properties are those of the individual elements	The properties are very different to those of the component elements
The components may be separated quite easily by physical means	The components can only be separated by one or more chemical reactions

Question

1. Make a list of some other common mixtures, stating what they are mixtures of.

Filtration

When a cup of tea is poured through a tea strainer you are carrying out a **filtering** process. **Filtration** is a common separation technique used in chemistry lab-oratories throughout the world. It is used when a solid needs to be separated from a liquid. For example, sand can be separated from a mixture with water by filtering through filter paper as shown in Figure 2.13.

The filter paper contains holes that, although too small to be seen, are large enough to allow the molecules of water through but not the sand particles. It acts like a sieve. The sand gets trapped in the filter paper and the water passes through it. The sand is called the residue and the water is called the **filtrate**.

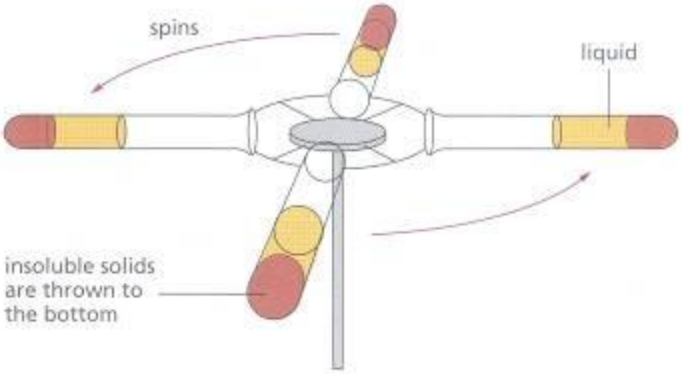
Decanting

Carrots do not dissolve in water. When you have boiled some carrots it is easy to separate them from the water by pouring it off. This process is called **decanting**. This technique is used quite often to separate an insoluble solid, which has settled at the bottom of a flask, from a liquid. A further example is the decanting of old red wine or port.

Figure 2.13 It is important when filtering not to overfill the filter paper.

Centrifuging

Another way to separate a solid from a liquid is to use a **centrifuge**. This technique is sometimes used instead of filtration. It is usually used when the solid particles are so small that they spread out (disperse) throughout the liquid and remain in **suspension**. They do not settle to the bottom of the container, as heavier particles would do, under the force of gravity. The technique of **centrifuging** or **centrifugation** involves the suspension being spun round very fast in a centrifuge so that the solid gets flung to the bottom of the tube (Figure 2.14a and b).



a The sample is spun round very fast and the solid is flung to the bottom of the tube.

b An open centrifuge.

Figure 2.14

Figure 2.15 Whole blood (top) is separated by centrifuging into blood cells and plasma (bottom).

The pure liquid can be decanted after the solid has been forced to the bottom of the tube. This method of separation is used extensively to separate blood cells from blood plasma (Figure 2.15). In this case, the solid particles (the blood cells) are flung to the bottom of the tube, allowing the liquid plasma to be decanted.

Evaporation

If the solid has dissolved in the liquid it cannot be separated by filtering or centrifuging. Instead, the solution can be heated so that the liquid evaporates completely and leaves the solid behind. The simplest way to obtain salt from its solution is by slow evaporation as shown in Figure 2.16.

Figure 2.16 Apparatus used to slowly evaporate a solvent.

Crystallisation

In many parts of the world salt is obtained from sea water on a vast scale. This is done by using the heat of the sun to evaporate the water to leave a **saturated solution** of salt known as brine. A saturated solution is defined as one that contains as much solute as can be dissolved at a particular temperature. When the solution is saturated the salt begins to **crystallise**, and it is removed using large scoops (Figure 2.17).

Figure 2.17 Salt is obtained in Rio de Janeiro, Brazil, by evaporation of sea water.

Simple distillation

If we want to obtain the solvent from a solution, then the process of **distillation** can be carried out. The apparatus used in this process is shown in Figure 2.18. Water can be obtained from salt water using this method. The solution is heated in the flask until it boils. The steam rises into the Liebig condenser, where it condenses back into water. The salt is left behind in the flask. In hot and arid countries such as Saudi Arabia this sort of technique is used on a much larger scale to obtain pure water for drinking (Figure 2.19). This process is carried out iii a desalination plant.

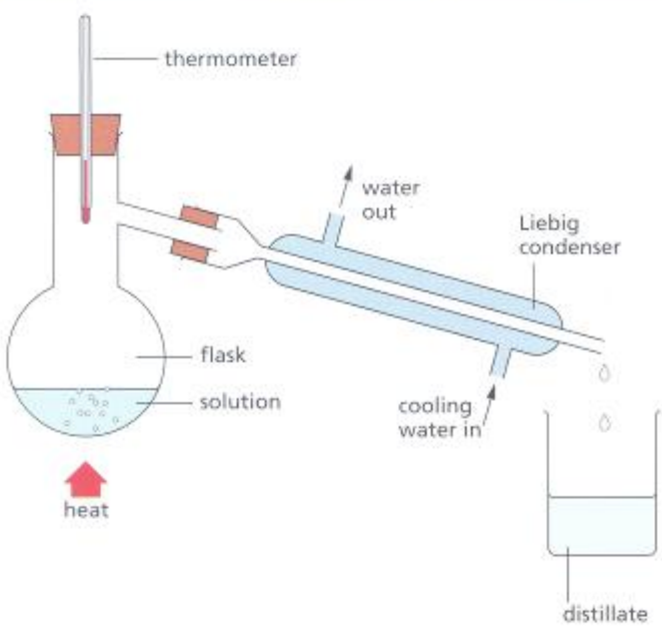


Figure 2.18 Water can be obtained from salt water by distillation.

Figure 2.19 This plant produces large quantities of drinking water in Bahrain.

Separating liquid/liquid mixtures

In recent years there have been many oil tanker disasters, just like the one shown in Figure 2.20. These have resulted in millions of litres of oil being washed into the sea. Oil and water do not mix easily. They are said to be **immiscible**. When cleaning up disasters of this type, a range of chemicals can be added to the oil to make it more soluble. This results in the oil and water mixing with each other. They are now said to be **miscible**. The following techniques can be used to separate mixtures of liquids.

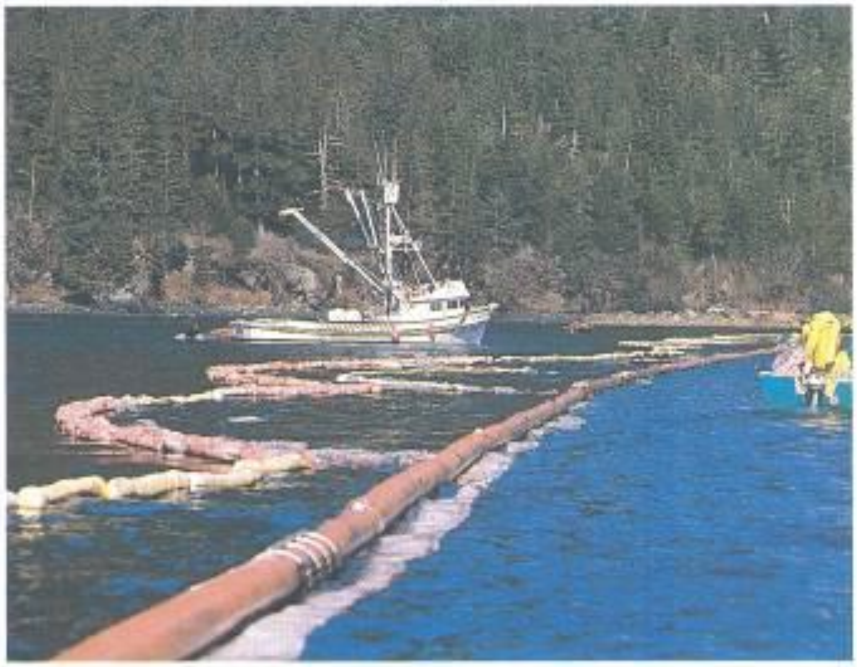


Figure 2.20 Millions of litres of oil are spilt in such disasters and the cleaning-up operation is a slow and costly process.

Figure 2.21 The water is more dense than the oil and so sinks to the bottom of the separating funnel. When the tap is opened the water can be run off.

Liquids which are immiscible

If two liquids are immiscible they can be separated using a **separating funnel**. The mixture is poured into the funnel and the layers allowed to separate. The lower layer can then be run off by opening the tap as shown in Figure 2.21.

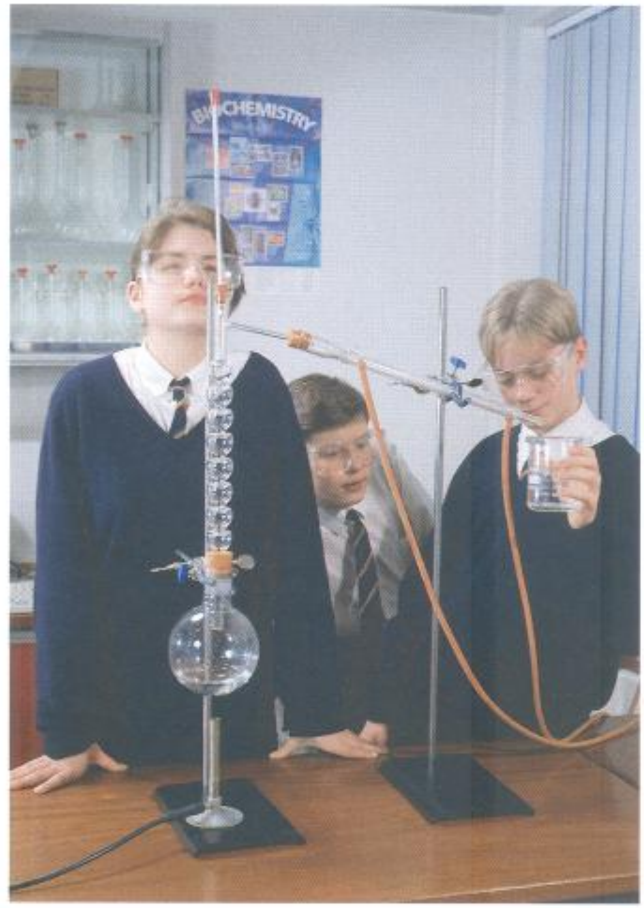
Liquids which are miscible

If miscible liquids are to be separated, then this can be done by **fractional distillation**. The apparatus used for this process is shown in Figure 2.22 and could be used to separate a mixture of ethanol and water.

Fractional distillation relies upon the liquids having different boiling points. When an ethanol and water mixture is heated the vapours of ethanol and water boil off at different temperatures and can be condensed and collected separately.

Ethanol boils at 78°C whereas water boils at 100°C. When the mixture is heated the vapour produced is mainly ethanol with some steam. Because water has the higher boiling point of the two, it condenses out from the mixture with ethanol. This is what takes place in the fractionating column. The water condenses and drips back into the flask while the ethanol vapour moves up the column and into the condenser, where it condenses into liquid ethanol and is collected in the receiving flask. When all the ethanol has distilled over, the temperature reading on the thermometer rises steadily to 100°C, showing that the steam is now entering the condenser. At this point the receiver can be changed and the condensing water can now be collected.

As well as separating miscible liquids such as crude oil (Figure 2.23a), fractional distillation can also separate individual gases, such as nitrogen, from the mixture we call air (Figure 2.23b).



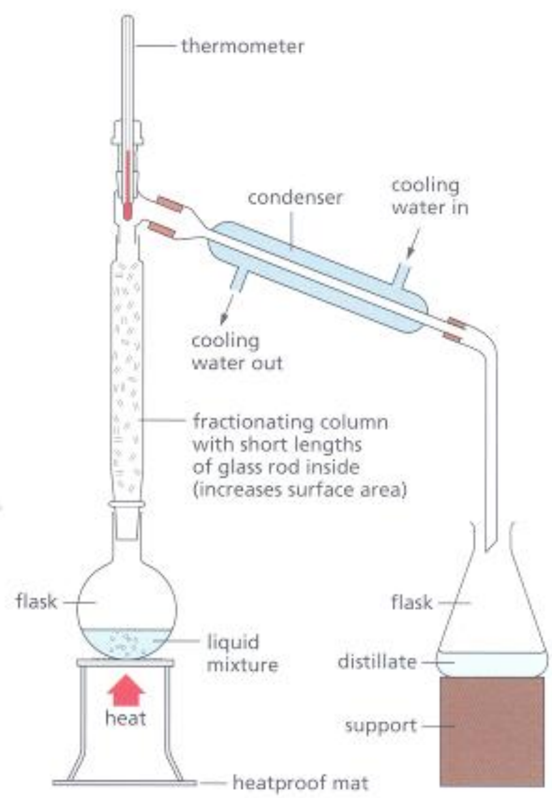


Figure 2.22 Typical fractional distillation apparatus.

Separating solid/solid mixtures

You saw earlier in this chapter that it was possible to separate iron from sulphur using a magnet. In that case we were using one of the physical properties of iron, that is, the fact that it is magnetic. In a similar way, it is possible to separate scrap iron from other metals by using a large electromagnet like the one shown in Figure 2.24.

It is essential that when separating solid/solid mixtures you pay particular attention to the individual physical properties of the components. If, for example, you wish to separate two solids, one of which sublimes, then this property should dictate the method you employ.

a Fractional distillation unit for crude oil.

b Gases from the air are extracted in this fractional distillation plant.

Figure 2.23

Figure 2.24 Magnetic separation of iron-containing materials.

In the case of an iodine/salt mixture the iodine sub-limes but salt does not. Iodine can be separated by heating the mixture in a fume cupboard as shown in Figure 2.25. The iodine sublimes and reforms on the cool inverted funnel.

Figure 2.25 Apparatus used to separate an iodine/salt mixture. The iodine sublimes on heating.

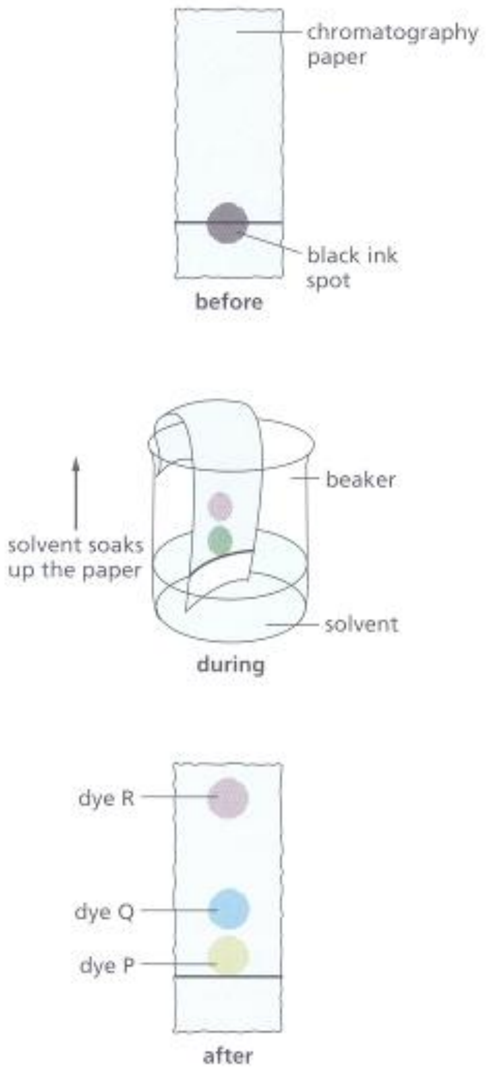
Chromatography

What happens if you have to separate two or more solids that are soluble? This type of problem is encountered when you have mixtures of coloured materials such as inks and dyes. A technique called **chromatography** is widely used to separate these materials so that they can be identified.

There are several types of chromatography; how-ever, they all follow the same basic principles. The simplest kind is paper chromatography. To separate the different-coloured dyes in a sample of black ink, a spot of the ink is put on to a piece of chromatography paper. This paper is then set in a suitable solvent as shown in Figure 2.26 on the next page.

As the solvent moves up the paper, the dyes are carried with it and begin to separate. They separate because the substances have different solubilities in the solvent and are absorbed to different degrees by the chromatography paper. As a result, they are separated gradually as the solvent moves up the paper. The **chromatogram** in Figure 2.26b shows

a Chromatographic separation of black ink.



b The black ink separates into three dyes: P, Q and R.

Figure 2.26

how the ink contains three dyes, P, Q and R. Numerical measurements known as **R_f values** can be obtained from chromatograms. An R_f value is defined as the ratio of the distance travelled by the solute (for example P, Q or R) to the distance travelled by the solvent.

Chromatography and electrophoresis (separation according to charge) are used extensively in medical research and forensic science laboratories to separate a variety of mixtures (Figure 2.27).

The substances to be separated do not have to be coloured. Colourless substances can be made visible by spraying the chromatogram with a **locating agent**. The locating agent will react with the colourless substances to form a coloured product. In other situations the position of the substances on the chromatogram may be located using ultraviolet light.

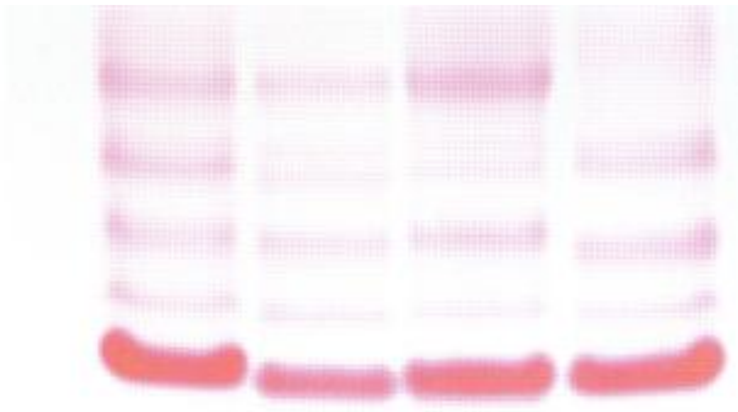


Figure 2.27 Protein samples are separated by electrophoresis in medical research laboratories.

Solvent extraction

Sugar can be obtained from crushed sugar cane by adding water. The water dissolves the sugar from the sugar cane (Figure 2.28). This is an example of **solvent extraction**. In a similar way some of the green substances can be removed from ground-up grass using ethanol. The substances are extracted from a mixture by using a solvent which dissolves only those substances required.

Figure 2.28 Sugar can be extracted from sugar cane by using a suitable solvent.

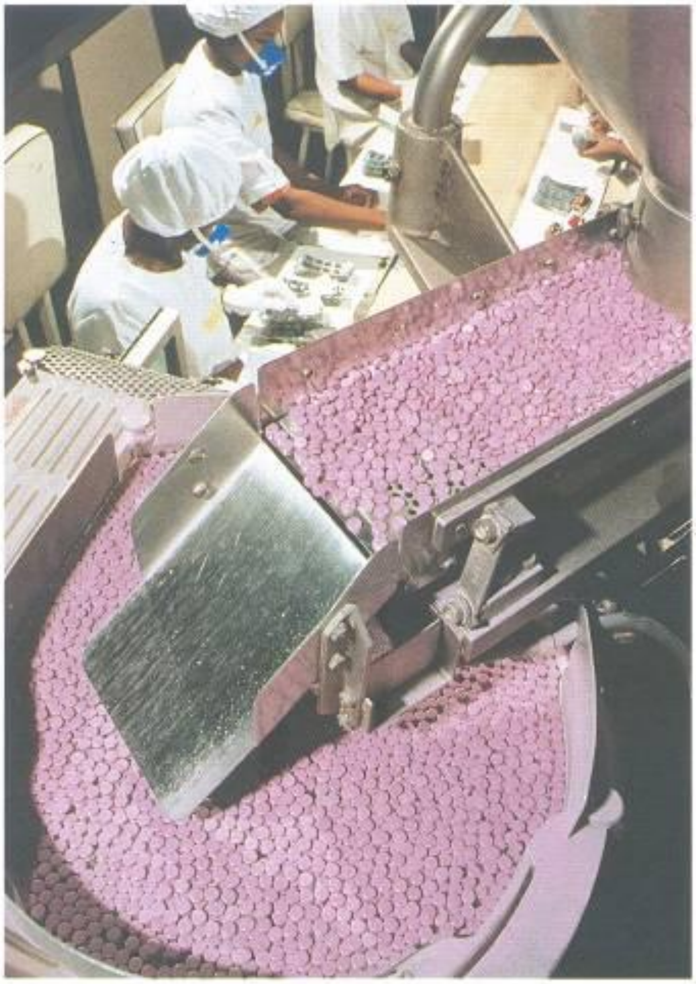


Figure 2.29 Drugs are manufactured to a high degree of purity by fractional crystallisation.

Drugs have to be manufactured to a very high degree of purity (Figure 2.29). To ensure that the highest possible purity is obtained, the drugs are dissolved in a suitable solvent and subjected to fractional crystallisation.

Questions

1. Use your research techniques (including the Internet) to obtain as many examples as you can in which a centrifuge is used.

2. What is the difference between simple distillation and fractional distillation?

3. Describe how you would use chromatography to show whether blue ink contains a single pure dye or a mixture of dyes.

4. Explain the following terms, with the aid of examples:

a. miscible
b. immiscible
c. evaporation
d. condensation
e. solvent extraction.

5. Devise a method for obtaining salt (sodium chloride) from sea water in the school laboratory.

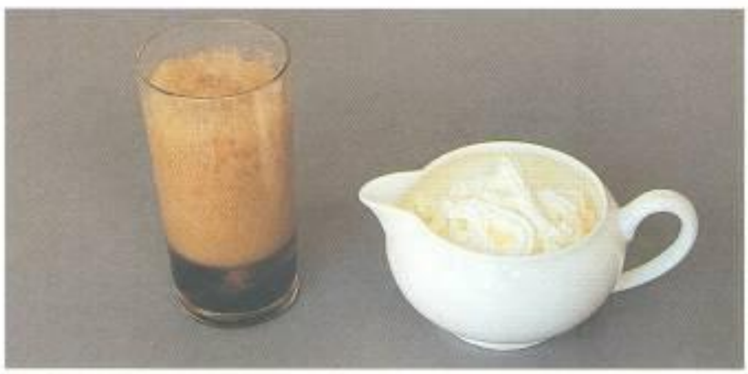
Gels, sols, foams and emulsions

Gels, sols, foams and emulsions are all examples of mixtures which are formed by mixing two substances (or phases) which cannot mix. These mixtures are often referred to as **colloids**. Colloids are formed if the suspended particles are between 1 nm and 1000 nm in size (1 nm = 1×10^{-9} m).

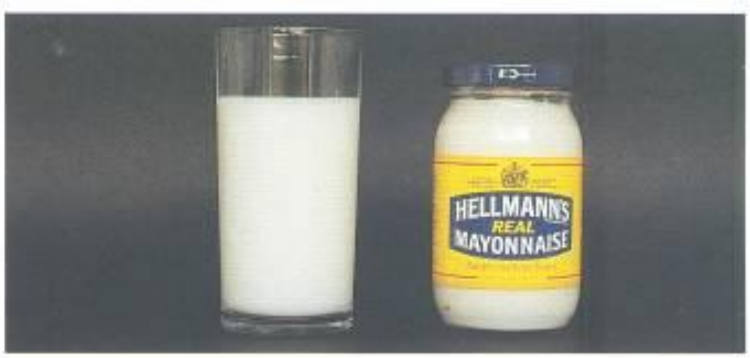
Generally colloids cannot be separated by filtration since the size of the dispersed particles is smaller than that of the pores found in the filter paper. Look closely at the food substances shown in Figure 2.30 to see examples of these mixtures.

a These jelly-like mixtures of solid and liquid in fruit jelly and cold custard are examples of 'gels'.

b Emulsion paint is an example of a 'sol'.



c These foams have been formed by trapping bubbles of gas in liquids or solids.



d Emulsions are formed by mixing immiscible liquids.

Figure 2.30

When you mix a solid with a liquid you sometimes get a gel. A gel is a semi-solid which can move around but not as freely as a liquid. Within a gel the solid makes a kind of network which traps the liquid and makes it unable to flow freely (Figure 2.31).

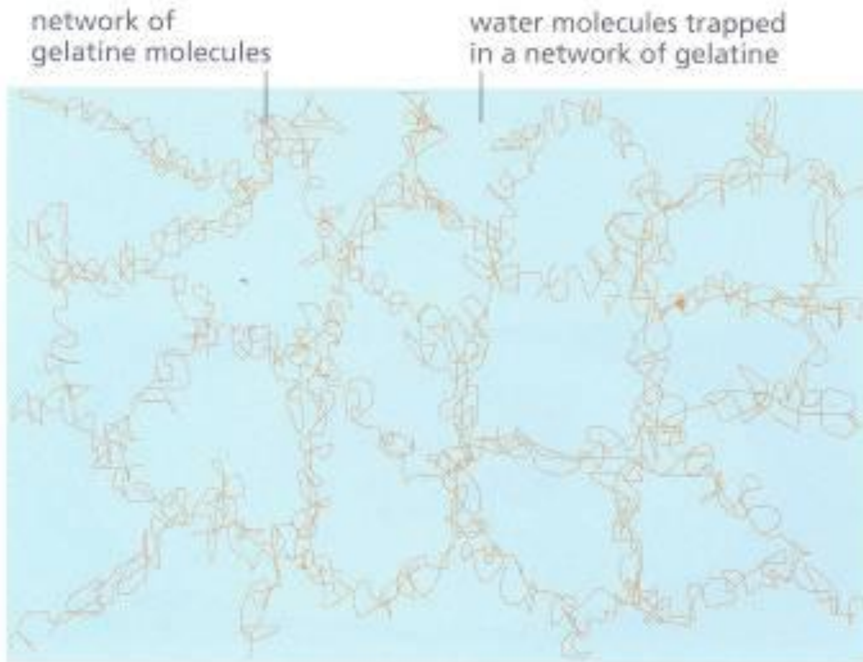


Figure 2.31 The network within a gel.

A gelatine gel is made with warm water. Gelatine is a protein. Proteins are natural polymers (Chapter 14) and the molecules of protein are very large. The large molecules disperse in water to form a gel. As the gelatine in water mixture cools, the gelatine molecules are attracted to each other and form a continuous network. In this way, the jelly you eat as a pudding is formed. The kind of gel which you put into your hair is made from water and an oil (Figure 2.32).

Figure 2.32 Hair gel is a mixture of water and an oil plus a perfume.

A **sol** is similar to a gel; however, the mixture will flow, for example emulsion paint, or PVA glue.

When you pour out a glass of fizzy drink, the frothy part at the top of the drink is a gas/liquid mixture called a **foam**. The gas, carbon dioxide, has formed tiny bubbles in the liquid but has not dissolved in it. If left to stand, foams like this one collapse as the tiny bubbles join together to form bigger bubbles which then escape. It is possible to form solid foams where the gases are trapped in a solid structure. This happens in foam rubber and bread (Figure 2.33).

Emulsions are mixtures of liquids which are immiscible. Earlier in this chapter you found out that when two liquids are immiscible they do not mix but form two different layers. Oil and water are like this but if you shake the mixture it becomes cloudy.

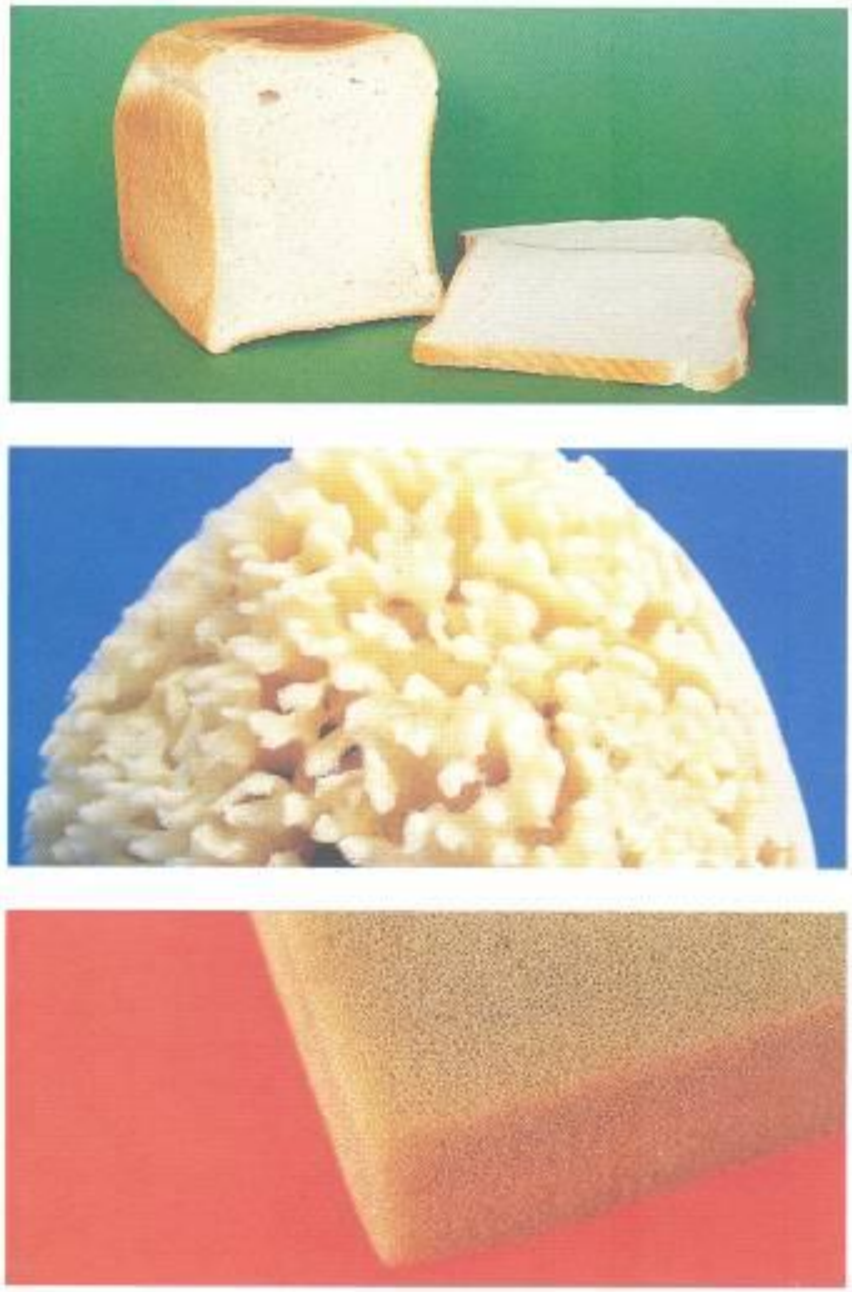


Figure 2.33 Examples of solid foams.

The apparent mixing that you see is due to the fact that one of the liquids has been broken into tiny drop-lets which float suspended in the other liquid. If the mixture of oil and water is now left to stand the two layers will re-form. To make emulsions, such as mayonnaise, an **emulsifier** is used to stop the droplets joining back together again to form a separate layer. The emulsifier used when making mayonnaise is egg yolk. If you examine the ingredients on the side of many packets found in your kitchen cupboard

you will find that emulsifiers have 'E-numbers' in the range E322 to E494. For example, ammonium phosphatide E442 is used as the emulsifier in cocoa and chocolate. Other food additives such as colourings and preservatives are also given E-numbers but in different ranges to that of the emulsifiers.

It is worth noting that gels, foams and emulsions are all examples of different kinds of solutions. In true solutions the two phases completely mix together but in these systems the two phases are separate.

To produce a stable colloid, the particles dispersed must not only be of the right size (1 – 1000 nm) but also be prevented from joining back together (coagulating). One way of doing this is to ensure that all the particles possess the same electrical charge. This causes the particles to repel one another.

A colloidal suspension can be destroyed by bringing the dispersed particles together. This process is known as **flocculation**. A method of doing this involves adding ionic substances such as aluminium chloride or aluminium sulphate to the particular colloid. The dispersed particles interact with the added highly charged ions and form particles which are large enough either to settle out under the force of gravity or simply be filtered out. During the treatment of water, aluminium sulphate is added to water prior to filtering to remove suspended solids (Figure 2.34).

Figure 2.34 Water is treated to remove suspended solids by the addition of aluminium sulphate.

Questions

1. Explain the following terms:

a. colloid
b. emulsifier
c. foam
d. 'E' number
e. sot.

2. Use your research skills (including the Internet) to obtain information about as many common gels, sols, foams and emulsions as you can, other than those given in the text.

Mixtures for strength

Composite materials

Composite materials are those that combine the properties of two constituents in order to get the exact properties needed for a particular job.

Glass-reinforced plastic (GRP) is an example of a composite material combining the properties of two different materials. It is made by embedding short fibres of glass in a matrix of plastic. The glass fibres give the plastic extra strength so that it does not break when it is bent or moulded into shape. The finished product has the lightness of plastic as well as the strength and flexibility of the glass fibres (Figure 2.35).

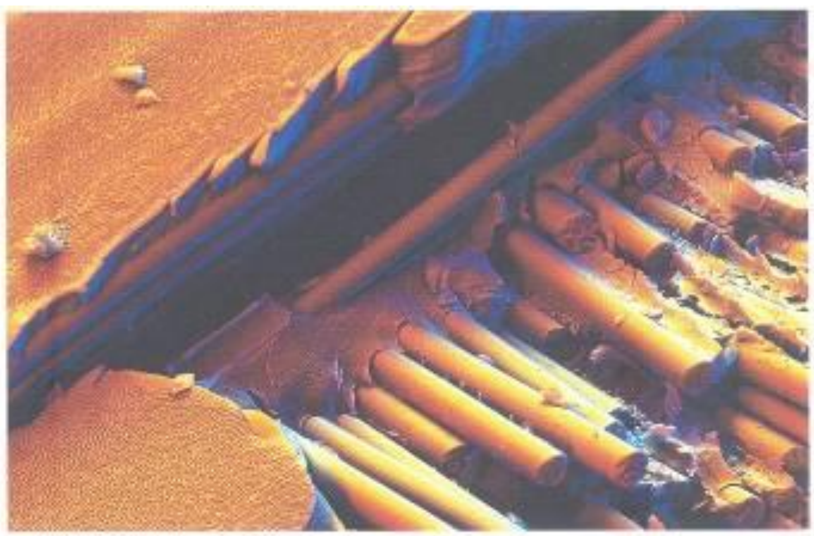


Figure 2.35 GRP consists of glass fibres (rod shapes) embedded in plastic, in this case polyester.

Figure 2.36 The glass-reinforced plastic used to make boats like this is a composite material.

With a little investigation you will find that many composite materials are found in the natural world. Our bones, for example, are a composite material formed from strands of the protein collagen and the mineral calcium phosphate (Figure 2.37). The calcium phosphate is hard and therefore gives strength to the bone. Another example is wood. Wood consists of cellulose fibres mixed with lignin (Figure 2.38), which is largely responsible for the strength of the wood.

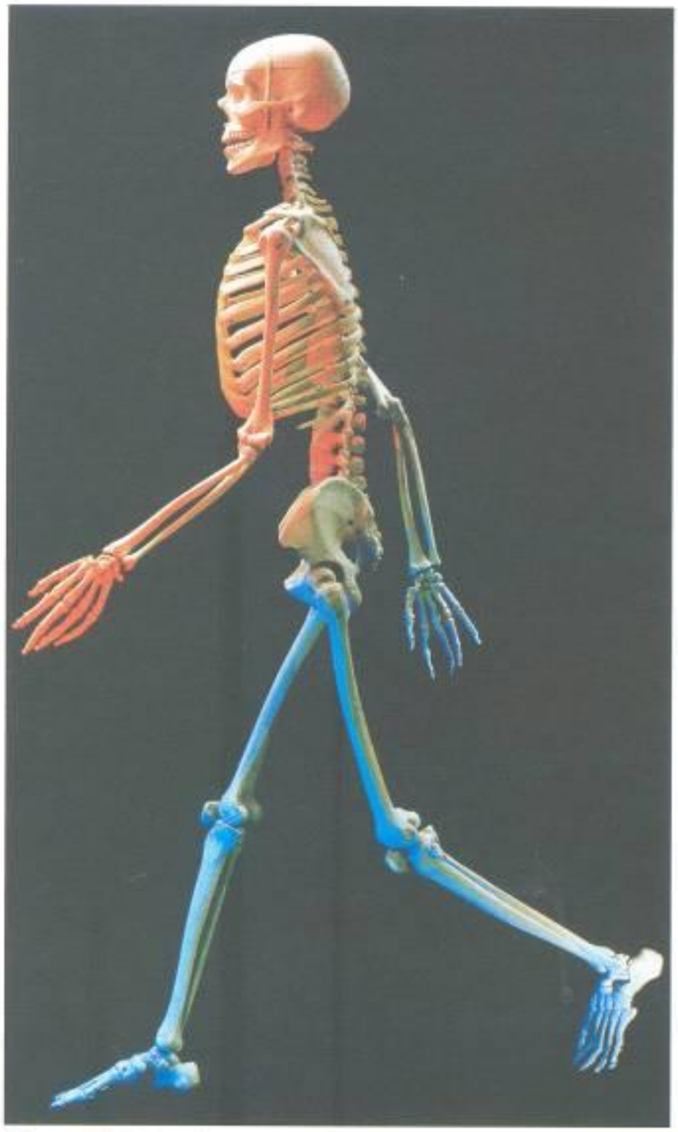


Figure 2.37 Bone is a composite material.

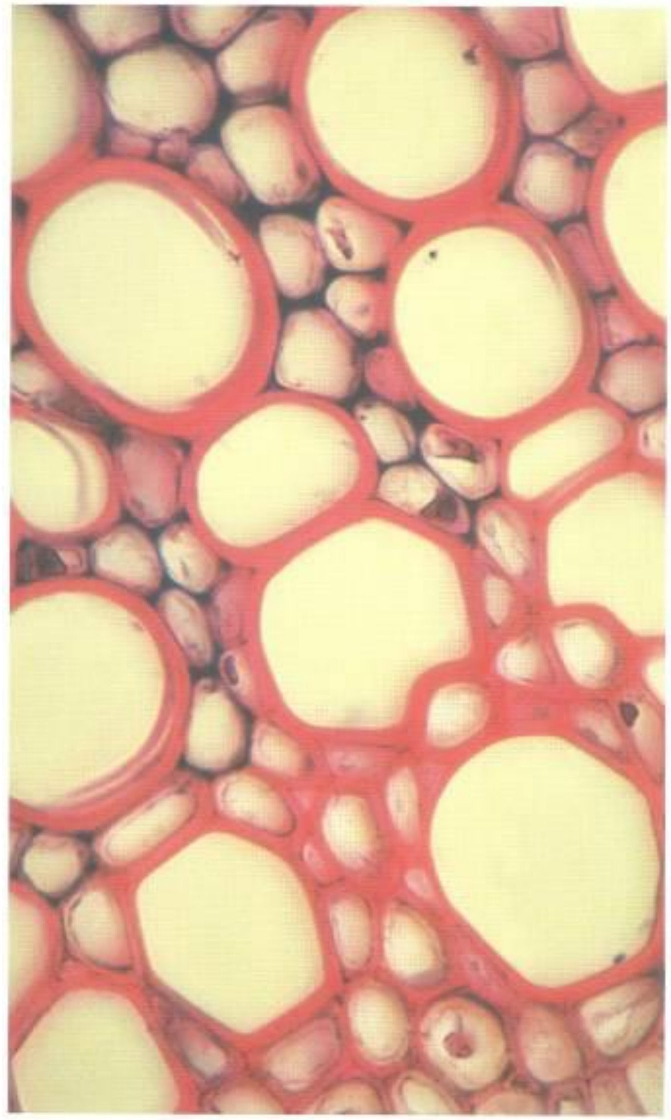


Figure 2.38 The combination of cellulose fibres and lignin makes the cell walls hard, thick and very strong. These properties reinforce the cells against collapse.

Questions

1. Why are composite materials often used instead of single materials?

2. Using the information in the text and any other information available to you, give a use other than those already mentioned for each of the following composite materials:

a. reinforced concrete
b glass-reinforced plastic
c. laminate
d. glass fibre.

Checklist

After studying Chapter 2 you should know and understand the following terms.

Atom The smallest part of an element that can exist as a stable entity.

Centrifuging The separation of the components of a mixture by rapid spinning. The denser particles are flung to the bottom of the containing tubes. The liquid can then be decanted off.

Chemical change A permanent change in which a new substance is formed.

Chemical formula A shorthand method of representing chemical elements and compounds.

Chromatography A technique employed for the separation of mixtures of dissolved substances.

Colloid Systems in which there are two or more phases, with one (the dispersed phase) distributed in the other (the continuous phase). One of the phases has particles in the range 1 to 1000 nm (1 nm = 1×10^{-9}m).

Composite materials Materials which combine the properties of two substances in order to get the exact properties required for a particular job.

Compound A substance formed by the combination of two or more elements in fixed proportions.

Crystallisation The process of forming crystals from a liquid.

Decanting The process of removing a liquid from a solid which has settled or from an immiscible heavier liquid by pouring.

Diatomic molecule A molecule containing two atoms, for example hydrogen, H_2, and oxygen, O_2.

Distillation The process of boiling a liquid and then condensing the vapour produced back into a liquid. It is used to purify liquids and to separate

mixtures of liquids.

Element A substance which cannot be further divided into simpler substances by chemical methods.

Emulsion The apparent mixing of two immiscible liquids by the use of an emulsifier which breaks down one of the liquids into tiny droplets. The droplets of this liquid float suspended in the other liquid so that they do not separate out into different layers.

Exothermic reaction A chemical reaction in which heat energy is produced.

Filtrate The liquid which passes through the filter paper during filtration.

Filtration The process of separating a solid from a liquid, using a fine filter paper which does not allow the solid to pass through.

Flocculation The destruction of a colloidal suspension by bringing the dispersed particles together.

Foam A mixture formed between a gas and a liquid. The gas forms tiny bubbles in the liquid but has not dissolved in it.

Gel A mixture formed between a solid and a liquid in which the solid forms a network which traps the liquid so that it cannot flow freely.

Immiscible When two liquids form two layers when mixed together, they are said to be immiscible.

Insoluble If the solute does not dissolve in the solvent it is said to be insoluble.

Instrumental techniques Instrumental methods of analysis that are particularly useful when the amount of sample is very small. Examples are atomic absorption spectroscopy and infrared spectroscopy.

Law of constant composition Compounds always have the same elements joined together in the same proportions.

Metals A class of chemical elements which have a characteristic lustrous appearance and which are good conductors of heat and electricity.

Miscible When two liquids form a homogeneous layer when mixed together, they are said to be miscible.

Mixture A system of two or more substances that can be separated by physical means.

Molecule A group of atoms chemically bonded together.

Monatomic molecule A molecule which consists of only one atom, for example neon and argon.

Non-metals A class of chemical elements that are typically poor conductors of heat and electricity.

Oxidation The process of combining with oxygen.

Redox reaction A reaction which involves the two processes of reduction and oxidation.

Reduction The process of removing oxygen.

Residue The solid left behind in the filter paper after filtration has taken place.

R_f value This is the ratio of the distance travelled by the solute to the distance travelled by the solvent in chromatography.

Saturated solution This is a solution which contains as much dissolved solute as it can at a particular temperature.

Sol A mixture formed between a solid and a liquid, which then forms a network that can flow.

Soluble If the solute dissolves in the solvent it is said to be soluble.

Solution This is formed when a substance (solute) disappears (dissolves) into another substance (solvent).

$$\text{solute} + \text{solvent} \xrightarrow{\text{dissolves}} \text{solution}$$

Elements, Compounds, and Mixtures

Additional questions

1. Define the following terms using specific examples to help with your explanation:

a. element
b. metal
c. non-metal
d. compound
e. molecule
f. mixture
g. flocculation
h. gel
i. foam
j. emulsion
k. sol

2. Which of the substances listed below are:

a. metallic elements?
b. non-metallic elements?
c. compounds?
d. mixtures?

Silicon, sea water, calcium, argon, water, air, carbon monoxide, iron, sodium chloride, diamond, brass, copper, dilute sulphuric acid, sulphur, oil, nitrogen, ammonia.

3. At room temperature and pressure (rtp), which of the substances listed below is:

a. a solid element?
b. a liquid element?
c. a gaseous mixture?
d. a solid mixture?
e. a liquid compound?
f. a solid compound?

Bromine, carbon dioxide, helium, steel, air, oil, marble, copper, water, sand, tin, bronze, mercury, salt.

4. A student heated a mixture of iron filings and sulphur strongly. He saw a red glow spread through the mixture as the reaction continued. At the end of the experiment a black solid had been formed.

a. Explain what the red glow indicates.

b. Give the chemical name of the black solid.

c. Write a word equation and a balanced chemical equation to represent the reaction which has taken place.

d. The black solid is a compound. Explain the difference between the mixture of sulphur and iron and the compound formed by the chemical reaction between them.

5. Name the method which is most suitable for separating the following:

a. the sediment formed at the bottom of a sherry bottle
b. oxygen from liquid air
c. red blood cells from plasma
d. petrol and kerosene from crude oil
e. coffee grains from coffee solution
f. pieces of steel from engine oil
g. amino acids from fruit juice solution
h. ethanol and water.

6. The table below shows the melting points, boiling points and densities of substances A to D.

Substance	Melting point/°C	Boiling point/°C	Density/ $g \cdot cm^{-3}$
A	1110	2606	9.1
B	-266	-252	0.07
C	40	94	1.6
D	-14	60	0.9

a. Which substance is a gas at room temperature?

b. Which substance is a liquid at room temperature?

c. Which substances are solids at room temperature?

d. Which substance is most likely to be a metal?

e. Which substance will be a liquid at -260°C?

f. What is the melting point of the least dense non-metal?

g. Which substance is a gas at 72°C?

7a. How many atoms of the different elements are there in the formulae of the compounds given below?

(i) nitric acid, HNO_3

(ii) methane, CH_4

(iii) copper nitrate, $Cu(NO_3)_2$

(iv) ethanoic acid, CH_3COOH

(v) sugar, $C_{12}H_{22}O_{11}$

(vi) phenol, C_6H_5OH

(vii) ammonium sulphate, $(NH_4)_2SO_4$

b. Balance the following equations:

(i) $Zn(s) + O_2(g) \rightarrow ZnO(s)$

(ii) $Fe(s) + Cl_2(g) \rightarrow FeCl_3(s)$

(iii) $Li(s) + O_2(g) \rightarrow Li_2O(s)$

(iv) $H_2(g) + O_2(g) \rightarrow H_2O(g)$

(v) $Mg(s) + CO_2(g) \rightarrow MgO(s) + C(s)$

8 Carbon-fibre-reinforced plastic (CRP) is used in the manufacture of golf clubs and tennis rackets.

a. What are composite materials?

b. Which two substances are used to manufacture this composite material?

Consider the data below.

Material	**Strength/ GPa**	**Stiffness/ GPa**	**Density/ $g \cdot cm^{-3}$**	**Relative cost**
Aluminium	0.2	75	2.7	low
Steel	1.1	200	7.8	low
CRP	1.8	195	1.6	high

c. Discuss the advantages and disadvantages of using the three materials above in the manufacture of golf clubs.